MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/2019

EME3046 – MECHANICS OF MATERIALS

(ME)

11 MARCH 2019
9.00am - 11.00am
(2 Hours, Open Book)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of 9 pages excluding the cover page and total of 5 Questions.
2. Questions 1 to 2 are **OPTIONAL**. Attempt only **ONE** out of the **TWO** questions.
3. Questions 3, 4 and 5 are **COMPULSORY**. You **MUST** attempt these questions.
4. All questions carry equal marks and the distribution of the marks for each question is given.
5. Write all your answers in the Answer Booklet provided.

OPTIONAL

Question 1:

The stress state at a point of a loaded member is described by the following stress tensor:

$$T = \begin{bmatrix} 6 & 2 & 2 \\ 2 & 0 & 4 \\ 2 & 4 & 0 \end{bmatrix}$$

(a) Determine the normal and shear stress on a plane whose unit normal vector is:

$$\vec{N} = \frac{1}{\sqrt{6}}\hat{i} + \frac{1}{\sqrt{3}}\hat{j} + \frac{1}{\sqrt{2}}\hat{k}$$

[10 marks]

(b) Determine the magnitude of the principal stresses.

[5 marks]

(c) Determine the magnitude and direction cosines of the normal stress on the octahedral plane.

[2 marks]

(d) Determine the magnitude of the shear stress on the octahedral plane.

[2 marks]

(e) Determine if the material (σ_U = 25MPa, Y = 15MPa) will fail, based on the following criteria:

i) The maximum principal stress criterion

ii) The Von Mises criterion

[6 marks]

Continued...

OPTIONAL

Question 2:

Figure 2 shows a rosette which is cemented to the free surface of an airplane wing made of an aluminium alloy (σ_U = 450MPa, E = 72 GPa, and ν = 0.33). Under load, the strain readings are $\varepsilon_a = \varepsilon_{xx} = 0.00250$, $\varepsilon_b = 0.00140$, and $\varepsilon_c = \varepsilon_{yy} = -0.00125$. Note that the stress components on the free surface are zero.

a) Determine all three principal stresses and orientation of the principal plane (in degrees).

[15 marks]

b) Determine the maximum shear stress and the corresponding orientation (in degrees). **[4 marks]**

c) Determine the factor of safety in the design by applying the maximum principal:

i) Stress criterion

ii) Strain criterion

[6 marks]

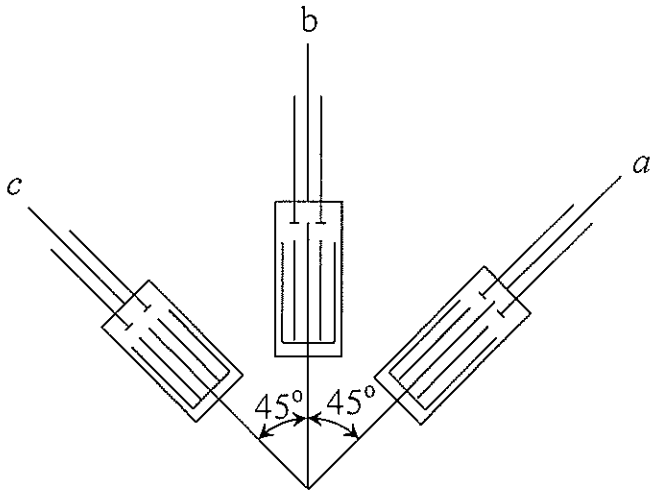

Figure 2

Continued...

COMPULSORY

Question 3:

(a) Figure 3(a) shows a horizontal statically indeterminate beam. A is a fixed end and B is a pinned end. x is any point along the length L of the beam. There is no eccentricity between the positions of A and B. The Young's Modulus E and cross-sectional second moment of area I of the beam are constant throughout its length.

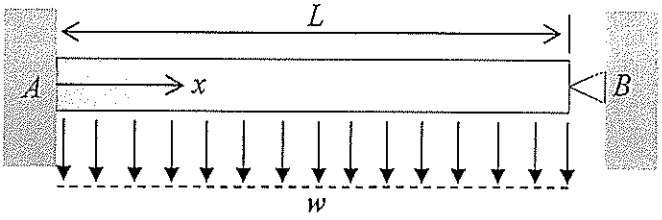

Figure 3(a)

The model of this beam can be simplified into the model shown in Figure 3(b). B_y and B_x are the reaction forces of the pinned support at B. A_y and A_x are the reaction forces of the fixed support at A, whereas M_A is its reaction moment.

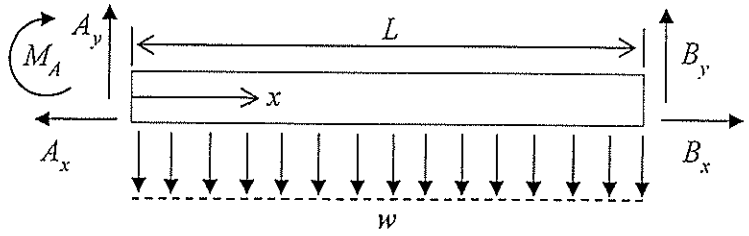

Figure 3(b)

The support reactions are related to each other, L and w through the following equations:

$$M_A = B_y L - 0.5wL^2$$
$$A_y = wL - B_y$$
$$A_x = B_x$$

The internal shear V_x at any point x along the beam length is as follows:

$$V_x = wL - B_y - wx$$

(i) Briefly describe how the model in Figure 3(b) contribute to the solution of this question.

[2 marks]

Continued...

(ii) Find V_x^2 , in terms of x, B_y , w and L.

[2 marks]

(iii)Find $\int_0^x V_x^2 dx$, in terms of x, B_y , w and L.

[2 marks]

(iv)Find $\frac{\partial}{\partial B_y}\left(\int_0^x V_x^2 dx\right)$ at $x = L$, in terms of B_y , w and L.

[3 marks]

(b) Referring to part (a), the following equation is needed to solve for the equation of the total strain energy of the beam, $(U_x)_{x=L}$.

$$\frac{\partial}{\partial B_y}\left(\int_0^x M_x^2\, dx\right)_{x=L} = \left(\frac{2}{3}B_y L^3\right) - (0.25wL^4)$$

The quantities of the beam in part (a) are:

Weight per length, $w = 0.05$ N/mm	Second moment of area, $I = 5 \times 10^4$ mm^4
Young's Modulus, $E = 250 \times 10^3$ MPa	Length of beam, $L = 1000$ mm
Shear Modulus, $G = 78 \times 10^3$ MPa	Cross sectional area, $A = 3 \times 10^3$ mm^2
Correction coefficient, $k = \frac{13}{15}$	

(i) Find $\frac{\partial U_x}{\partial B_y}$ at $x = L$, in terms of B_y , w, L, E, I, k, G and A.

[3 marks]

(ii) The deflection at B (i.e. $x = L$) is zero.
Find B_y in terms of w, L, E, I, k, G and A.

[3 marks]

(iii)Determine the value of B_y in units of Newton (N).

[3 marks]

(iv)Determine the value of A_y in units of N.

[1 mark]

(v) Determine the value of M_A in units of Newton-meter (N·m).

[1 mark]

(c) Referring to part (a), there are the reactions A_x and B_x. In this case, **they are not zero.**

(i) Describe a reason for why the reactions are not zero.
(Hint: parts (a) and (b) are about the deflection of the beam in the vertical direction. Consider any changes in the horizontal direction, i.e. along the beam axis.)

[2 marks]

(ii) The axial strain in the beam is 5.952381×10^{-10}. Calculate the values of A_x and B_x.

[3 marks]

Continued...

COMPULSORY

Question 4:

(a) Figure 4(a) shows the cross section of a prismatic object under torsion. The prismatic bar has a solid cross section of an equilateral triangle.

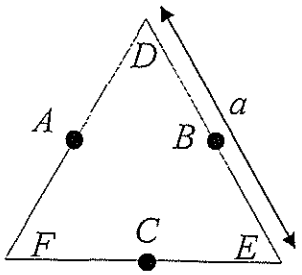

Figure 4(a)

Length of side of triangle $a = 10$ mm
Torque applied $T = 5.0 \times 10^3$ N-mm

(i) Describe a practical real-life example of an object that is a solid triangular prism and is used under torsion.
(*Note: This example should not be a kind of food or snack.*)

[2 marks]

(ii) Find the torsion constant of the prismatic object.
(*Note: Read the entry for "torsion constant" in the Glossary of the Appendix.*)

[1 mark]

(iii) Find the maximum torsional stress τ_{max} for the cross section.

[1 mark]

(iv) Based on the answer for part (iii), briefly explain an example of a material that is suitable for this object.

[2 marks]

(v) According to analytical studies like Roark's work in 1954, the maximum torsional stress τ_{max} occur at the middle points of the sides of the triangle, as shown in Figure 4(a).
Briefly describe one example of a condition that lets this happen.

[3 marks]

Continued...

(b) In a different case, the torque T in part (a) is applied to the object in Figure 4(a) through tightly holding the object at points D, E and F, and then turning. The tight holding applies the forces F_1, F_2 and F_3 on these points, respectively.

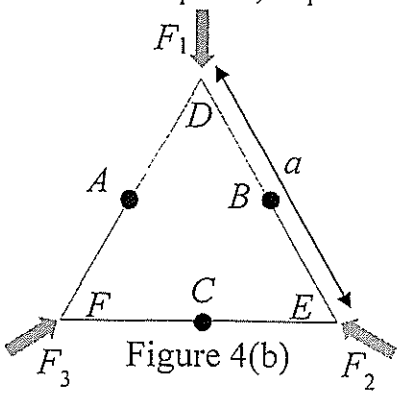

Figure 4(b)

(i) Describe a risk of tightly holding the object at points D, E and F while applying the torque.

[3 marks]

(ii) If the torque is applied in this way, there is an additional form of stress on the object. State what this form of stress is, and the cause of this stress.

[2 marks]

(c) Figure 4(c) shows an experiment to determine the yield strength in torsion of a solid cylindrical specimen. The properties of the specimen are:

Radius of cylindrical specimen	$r = 5$ mm
Torque	$T = 12500\ N{\cdot}mm$
Modulus of rigidity	$G = 1$ GPa

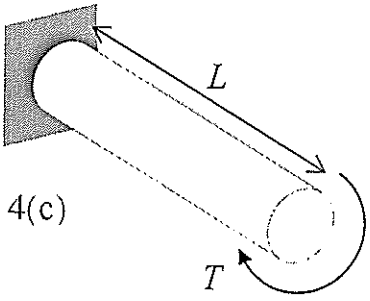

Figure 4(c)

(i) Find the polar moment of inertia J of the specimen in mm^4.

[1 mark]

(ii) Find the maximum torsional stress τ_{max} in the specimen.

[1 mark]

Continued...

(iii) State the region of the object where the maximum torsional stress τ_{max} occurs, and explain this.

[2 marks]

(iv) Describe how the region of the specimen in part (iii) would fail. (Hint: consider how this region looks like when the specimen fails.)

[2 marks]

(v) Describe a method of how to apply the torque T without causing stress concentration on the surface of the specimen.
(Hint: consider how the specimen can be secured and twisted without damaging its surface. Also, the specimen can become bigger than that shown in Figure 4(c).)

[2 marks]

(vi) When the torque T is applied on the specimen, the specimen should not twist for more than one full revolution (i.e. 360°).
Determine the maximum length that the specimen can have.

[3 marks]

Continued...

COMPULSORY

Question 5:

(a) Figure 5(a) shows a simplified representation of a structure. This structure is composed of four struts with a load W on top. The struts are long slender columns. The struts are spaced at equal distances to each other. The load W is equally distributed among the struts. If a strut is removed, the load W does not change in amount but is redistributed equally again among the remaining struts. The size of the load W is not a factor in this scenario. Any remaining struts support the load W as long as they have not buckled. The column configurations are fixed-end and free-end with rotation-fixed. The physical quantities of the struts and load W are as follows:

Load	$W = 4 \times 10^3$ N
Modulus of elasticity	$E = 250 \times 10^3$ MPa
Second moment of area of each strut	$I = 5 \times 10^6$ mm^4
Length of each strut	$L = 25 \times 10^3$ mm

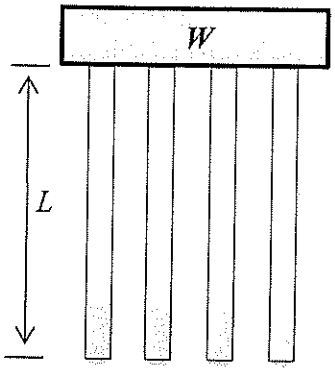

Figure 5(a)

(i) Find the critical load for each strut, P_{cr}.

[2 marks]

(ii) Based on details that are given, state an example of a real-life structure that has such a design and describe the practical reason for its design.

[3 marks]

(iii) Find how many struts can be removed **before** the structure becomes at risk from buckling.

[3 marks]

(iv) A demolition company wants to remove the structure by removing struts until the structure topples. (See Glossary section in appendix for meaning of "topple".) Referring to the answer in (ii), explain a reason for why the company would want to do this instead of something else.

[3 marks]

(v) The load W is equally distributed among the struts, and is redistributed when the struts are removed. Describe how this could be possible in real life.

[2 marks]

Continued...

(b) Figure 5(b) shows a simplified representation of a tall and slender object. W_a is the weight of the object, acting along its cross sectional axis. The object has a fixed-end and a free-end with free rotation.

The object is at risk of buckling under its own weight. (See appendix for the equation about the height at which a column buckles under its own weight.)

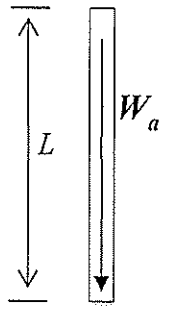

Figure 5(b)

The physical quantities in this scenario are as follows:

$E = 200$ GPa $\quad I = 0.01$ m^4
$\rho = 7750$ kg /m^3 $\quad A = 0.04$ m^2

E, modulus of elasticity ; I, second moment of area of the object;
ρ, density of the object ; A, cross sectional area of the object

(i) Find the maximum height l_{max} that the object can reach before it buckles under its own weight.

[2 marks]

(ii) Find the weight W_{max} of the object at the maximum height.

[2 marks]

(iii) State an example of a real-world object that resembles the object in Figure 5(b). Describes its practical purpose and how this purpose contributes to its weight.

[3 marks]

(iv) Find the slenderness ratio of the column.

[2 marks]

(v) Consider the scenario that the object has to support more loads at its top, in addition to supporting its own weight.
State whether the object can support more loads or not when it is close to its maximum height, and explain this statement.
Also, mention an example of a solution to have the object support more loads.

[3 marks]

End of Paper